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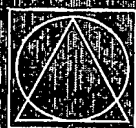
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**Applicant:** Sinvent AS  
N-7465 Trondheim

**Attorney:** Svein Hofseth  
Norsk Hydro ASA  
N-0240 Oslo

**Inventors:** Kåre Aflekt  
Sigurd Einbus veg 3  
N-7036 Trondheim

Armin Hafner  
Veimester Kroghs gate 26B  
N-7052 Trondheim

Arne Jakobsen  
Rådmann Hammers vei 16D  
N-7020 Trondheim

Petter Nekså  
Gløshaugveien 6  
N-7030 Trondheim

Jostein Pettersen  
Johannes Minsaas vei 12  
N-7053 Trondheim

Håvard Rekstad  
Peder Kroghs vei 12  
N-7030 Trondheim

Geir Skaugen  
Dalen Hageby 31  
N-7044 Trondheim

Trond Andresen  
Abelsborg gate 11  
N-7036 Trondheim

Espen Tøndell  
Saturnveien 11  
N-7036 Trondheim

Munan Elgsæther  
Leistadgrenda 5  
N-7047 Trondheim

**Title:** Improved vapour compression heat pump system.

**Field of invention**

The present invention relates to vapour compression heat pump system including a compressor, a heat rejector, an expansion means and a heat absorber connected in a closed circulation circuit that may operate with supercritical high-side pressure, using carbon dioxide or a mixture containing carbon dioxide as the refrigerant in the system.

**Description of prior art and background of the invention**

Conventional vapour compression systems reject heat by condensation of the refrigerant at subcritical pressure given by the saturation pressure at the given temperature. When using a refrigerant with low critical temperature, for instance CO<sub>2</sub>, the pressure at heat rejection will be supercritical if the temperature of the heat sink is high, for instance higher than the critical temperature of the refrigerant, in order to obtain efficient operation of the system. The cycle of operation will then be transcritical, for instance as known from WO 90/07683.

WO 94/14016 and WO 97/27437 both describe a simple circuit for realising such a system, in basis comprising a compressor, a heat rejector, an expansion means and an evaporator connected in a closed circuit. CO<sub>2</sub> is the preferred refrigerant for both of them.

Heat rejection at super critical pressures will lead to a refrigerant temperature glide. This can be applied to make efficient hot water supply systems, e.g. known from US 6,370,896 B1.

Ambient air is a cheap heat source which is available almost everywhere. Using ambient air as heat source, vapour compression systems often get a simple design that is cost efficient. However, at high ambient temperatures, the exit temperature of the compressor gets low, for instance around 70°C for a trans-critical CO<sub>2</sub> cycle. Desired temperature of tap water is often 60-90°C. The exit temperature can be increased by increasing the exit pressure, but this will lead to a drop in system performance. Another drawback with increasing pressures is that components will be more costly due to higher design pressures.

Another drawback occurring at high ambient temperatures is that superheat of the compressor suction gas, which normally is provided by an internal heat exchanger, is not possible as long as evaporation temperature is higher than the heat rejecter refrigerant outlet temperature. Hence, there is a risk for liquid entering the compressor.

A strategy to solve these problems is to regulate the evaporation temperature to always be below heat rejecter refrigerant outlet temperature. This will make superheat of the suction gas possible and also increase the compressor discharge temperature for improved hot water production, but the system energy efficiency will be poor since suction pressure will be lower than necessary.

US 6,370,896 B1 presents a solution to these problems. The idea is to use a part of the heat rejecter to heat the compressor suction gas. The full flow on the high pressure side is heat exchanged with the full flow on the low pressure side. This will ensure a superheat of compressor suction gas, and thereby secure safe compressor operation, but the system efficiency will drop compared to a system which compresses saturated gas (if possible) and which operates with a higher exit pressure to achieve a sufficient compressor discharge temperature. The suggested solution is hence more of operational importance.

### **Summary of the invention**

A major object of the present invention is to make a simple, efficient system that avoids the aforementioned shortcomings and disadvantages.

The invention is characterized by the features as defined in the accompanying independent claim 1.

Advantageous features of the invention are further defined in the accompanying independent claims 2 – 9.

The present invention is based on the system described above, comprising at least a compressor, a heat rejecter, an expansion means and a heat absorber. By superheating the compressor suction gas temperature, the compressor exit temperature can be increased without increasing the exit pressure and hot water at desired temperatures can be produced. By using a split refrigeration flow at appropriate temperature from the heat rejecter, it is possible to superheat the compressor suction gas, for instance using a counter flow heat exchanger. After heating the compressor suction gas, the split flow is expanded directly to the low pressure side of the system. In this way, the two parts of the heat rejecter will have different heating capacity per kilogram water flow due to lower flow in the latter part. It is hence possible to adapt a water heating temperature profile even closer to the refrigerant cooling temperature profile. Hot water can be produced with a lower high side pressure, and hence with a higher system efficiency.

### **Brief description of the drawings.**

The invention will be further described in the following by way of examples only and with reference to the drawings in which,

Fig. 1 illustrates a simple circuit for a vapour compression system,

Fig. 2 shows a temperature entropy diagram for carbon dioxide with examples of operational cycles for hot water production.

Fig. 3 a schematic diagram showing an example of a modified cycle to improve system performance and operating range.

Fig. 4 a schematic diagram showing another example of a modified cycle to improve system performance and operating range.

Fig. 5 shows a temperature entropy diagram for carbon dioxide with examples of temperature profiles for the heat rejecter.

### **Detailed description of the invention**

Fig. 1 illustrates a conventional vapour compression system comprising a compressor 1, a heat rejector 2, an expansion means 3 and a heat absorber 4 connected in a closed circulation system. When using for instance CO<sub>2</sub> as refrigerant, the high-side pressure will normally be supercritical in hot water supply systems in order to achieve efficient hot water generation in the heat rejecter, illustrated by circuit A in figure 2. Desired tap water temperatures are often 60 – 90°C, and the refrigerant inlet temperature to the heat rejecter 2, which is equal to or lower than the compressor discharge temperature, has to be above desired hot water temperature.

Ambient air is often a favourable alternative as heat source for heat pumps. Air is available almost everywhere, it is inexpensive, and the heat absorber system can be made simple and cost efficient. However, at increasing ambient temperatures, the evaporation temperature will increase and the compressor discharge temperature will drop if compressor discharge pressure is constant, see circuit B in figure 2. The compressor discharge temperature may drop below desired tap water temperature. Tap water production at desired temperature will then be impossible without energy supply from other heat sources.

One way to increase discharge temperature is to increase high side pressure, see circuit C in figure 2. But this will cause a reduction of system efficiency.

A conventional way to superheat the suction gas is to use an internal heat exchanger 5, see figure 3. But for instance when heating tap water, the refrigerant is cooled down close to net water temperature, typically around 10°C, in the heat rejecter 2. If the evaporation temperature is above this temperature, suction gas will be cooled down instead of superheated, see figure 2. Liquid would enter in to the compressor 1, causing severe problems. It is important to avoid using the internal heat exchanger 5 when the evaporation temperature is equal to or higher than the net water temperature.

The present invention will secure a suction gas superheat irrespective of ambient temperature. When the evaporation temperature, or other appropriate temperatures, reaches a predetermined level, a split refrigerant flow from the heat rejecter 2 at a suitable temperature, is carried to a heat exchanger, for instance a counter flow heat exchanger, for compressor suction gas heating. The compressor discharge temperature will increase, and hot water may be produced at high system efficiency, see circuit D in figure 2. After heating the compressor suction gas, the split stream is expanded directly down to the low pressure side.

### Example 1

One possible arrangement for the invention is to lead the split refrigerant flow through an already existing internal heat exchanger 5. An arrangement for bypassing the main flow outside the internal heat exchanger 5, and leading the split flow through the internal heat exchanger 5, then has to be implemented. There are various solutions for this arrangement. One alternative is to use two three-way valves 6' and 6'', as indicated in figure 3. One or both of the three-way valves may for instance be replaced by two stop valves. The split refrigerant flow is expanded directly to the low pressure side through an orifice 7 downstream of the internal heat exchanger 5. The orifice 7 may be replaced by other expansion means, and valves may be installed upstream and/or downstream of the expansion means for improved flow control through the expansion means 7.

### Example 2

Another possibility is to install a separate heat exchanger 8, for instance a counter flow heat exchanger, for suction gas heating. This is illustrated in figure 4. When the evaporation temperature, or other usable temperatures, reaches a predetermined level, a split refrigerant flow is led through the suction gas heater 8 by opening the valve 10. This valve may be installed anywhere on the split refrigerant line. The split refrigerant flow is expanded directly to the low pressure side through an expansion mean, for instance an orifice 7 as indicated in figure 4. The internal heat exchanger 5 can be avoided either by an arrangement on the high pressure side indicated by the three way valve 9', or a equivalent arrangement on the low pressure side as indicated by dotted lines in figure 4.

Suction gas superheat may be controlled by regulation of the split refrigerant flow. This can for instance be performed by a metering valve in the split refrigerant flow line.

Another option is to apply a thermal expansion valve.

As explained above, the invention will improve the energy efficiency at high heat source temperatures, indicated by circuit D in figure 2. The reason is that by applying the present invention the high side pressure may be further reduced compared to what normally would be optimum pressure. This is illustrated in figure 5. The first part of the heat rejecter 2' will have a higher heating capacity relative to the water flow, compared to the latter part of the heat rejecter 2''. The temperature profile for the water heating will be even better adapted to the cooling profile of the refrigerant, see water heating profile b in figure 5. Applying a conventional system will lead to the water heating profile a. As can be seen from figure 5, a temperature pinch will occur in the heat rejecter 2. High side pressure will then have to be increased. With the present invention, it is possible to produce hot water at desired temperature with a lower high side pressure, leading to an even more energy efficient system.





### Claims

1. A vapour compression heat pump system including at least a compressor (1), a heat rejecter (2), an expansion means (3) and a heat absorber (4) connected in a closed circulation circuit that may operate with supercritical high-side pressure, and that carbon dioxide or a refrigerant mixture containing carbon dioxide is applied as the refrigerant in the system,  
**characterized** in that the system heat pump is improved by controlling the compressor's (1) suction gas superheat.
2. System according to claim 1, **characterized** in that the suction gas superheat is increased when the temperature of the heat source is above a predetermined level.
3. System according to any of the preceding claims 1-2, **characterised** in that a limitation for the superheat is the compressor's discharge temperature, which can not exceed a predetermined level.
4. System according to any of the preceding claims 1-3, **characterized** in that a split refrigerant flow from the heat rejecter (2) is used for the compressor's (1) suction gas superheating.
5. System according to any of the preceding claims 1-4, **characterized** in that the split refrigerant flow from the high pressure side is expanded directly down to heat absorber pressure after suction gas heating.
6. System according to any of the preceding claims 1-5, **characterized** in that the split refrigerant flow is regulated in order to control the suction gas superheat.

7. System according to any of the preceding claims 1-6, **characterized** in that a counter flow heat exchanger (5, 8) is used to heat the compressor suction gas.
8. System according to any of the preceding claims 1-7, **characterized** in that the counter flow heat exchanger may be a separate unit or the internal heat exchanger if already installed.



**Abstract**

Vapour compression heat pump system including at least a compressor (1), a heat rejecter (2), an expansion means (3) and a heat absorber (4) connected in a closed circulation circuit that may operate with supercritical high-side pressure. Carbon dioxide or a refrigerant mixture containing carbon dioxide is applied as the refrigerant in the system. The system heat pump efficiency is improved by controlling the compressor's (1) suction gas superheat.



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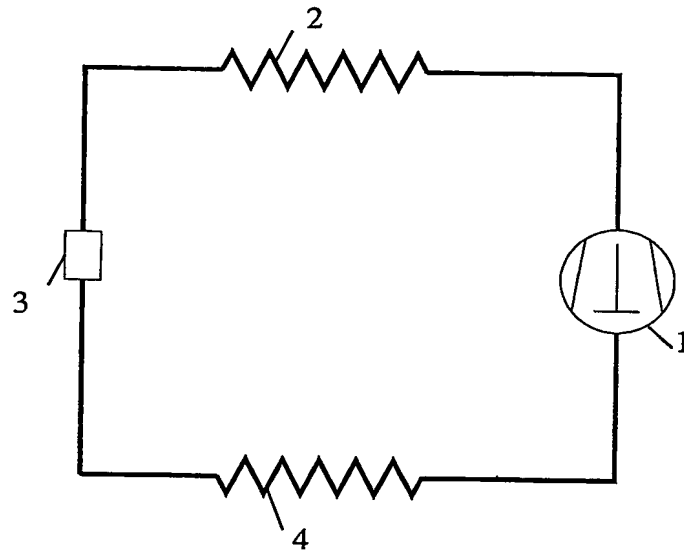


Fig. 1

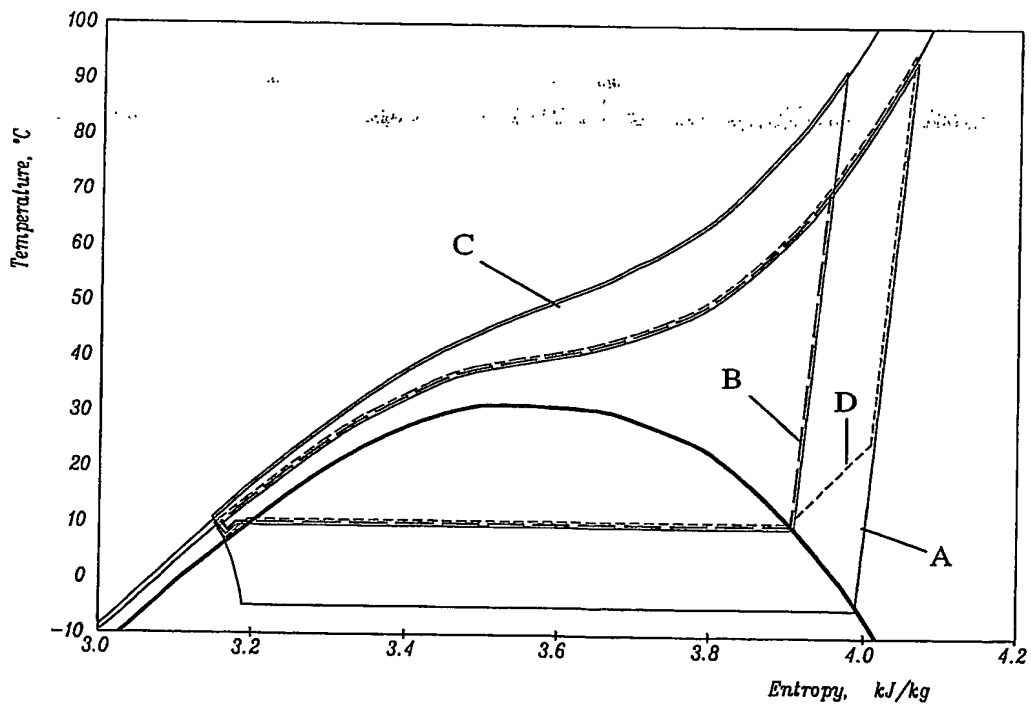


Fig. 2



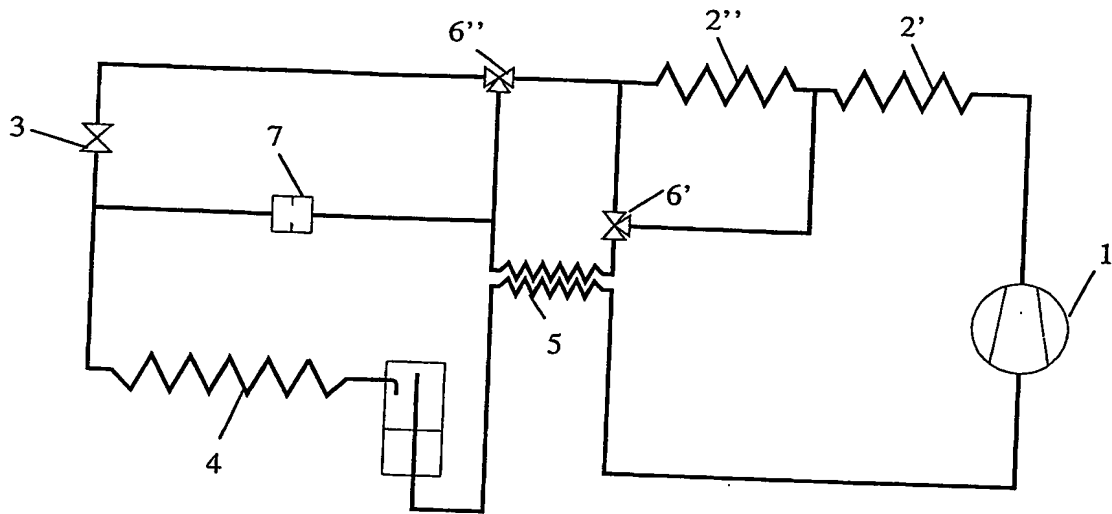


Fig. 3

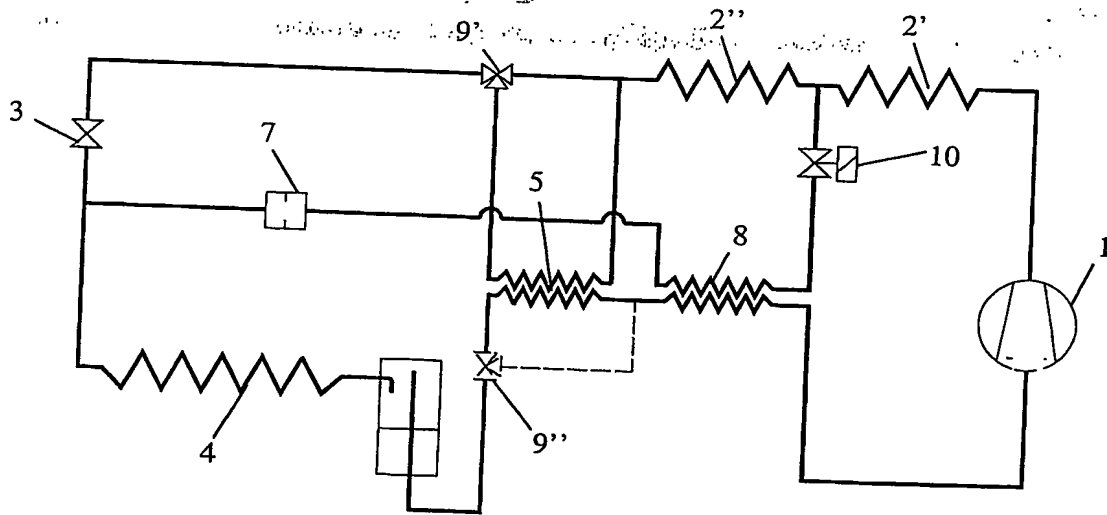
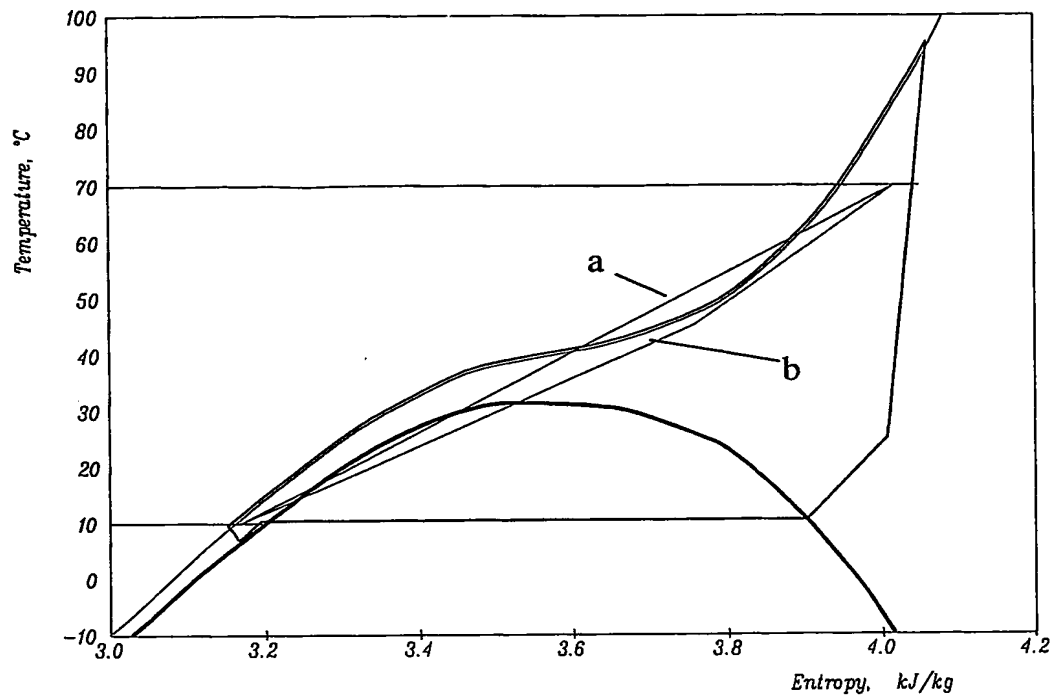
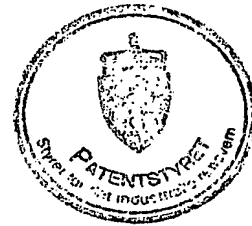


Fig. 4



**Fig. 5**

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